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Effects of Natural and Synthetic Soil Conditioners on Soil Moisture Retention and Maize Yield

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Abstract

The efficacy of a natural soil conditioner, Coco-Peat (C-P), and synthetic soil conditioners, Terawet (T-200) and Teraflow (T-F), in improving soil moisture content were examined on five Ghanaian soil series (*Akroso, Akuse, Amo, Hake* and *Oyarifa*). In general, the water retention of T-200 and C-P treated soils were similar but significantly higher ($p < 0.001$) than that of T-F and the control (C-T) treated soils, which were also similar on all the test soils. The dry matter yields of the test crop (maize) were 5.4, 5.2, 4.5 t ha^{-1} on T-200, C-P and T-F treated soils, respectively, on *Akroso series*. These yields were 36%, 31% and 5%, respectively, more than those of the control treatment. On *Akuse series* even though T-200 and T-F gave higher dry matter yields than the control, the differences were not significant, only C-P treatment gave significantly higher ($p < 0.001$) yield than the control. On *Amo series*, dry matter yields of 6.1, 5.8 and 4.9 t ha^{-1} on T-200, C-P and T-F treated soils, respectively, were 38%, 31% and 10% more than the control treatment. On *Hake series*, T-200, C-P and T-F treatments improved dry matter yields by 45%, 32% and 12%, respectively, over that of the control. The greatest effect of the polymeric absorbents was observed on the sandy/clay/loam *Oyarifa series*. The treatments T-200, C-P and T-F improved dry matter yields by 92%, 81% and 4%, respectively, over the control treatment. The results indicate that the differences in yields over the control were due to the improved water retention ability of the soils amended with the polymeric absorbents.

Introduction

Efficient management of soil moisture is important for agricultural production in the light of scarce water resources. Soil conditioners, both natural and synthetic, contribute significantly to provide a reservoir of soil water to plants on demand in the upper layers of the soil where the root systems normally develop. These polymeric organic materials and hydrogels apart from improving the soil physical properties, also serve as buffers against temporary drought stress and reduce the risk of plant failure during establishment (De Boodt, 1990; Johnson & Leah, 1990). This is achieved by means of reduction of evaporation through restricted movement of water from the sub-surface to the surface layer (Ouchi *et al.,* 1990).

The decomposition of organic polymeric products in soil by microbial activities results in compounds such as polysaccharides and polyuronides (Hillel, 1980). These promote soil aggregate stability by gluing particles together within aggregates, as well as coating aggregate surfaces. One of the recently developed organic soil conditioners, Coco-Peat, has been observed to greatly improve the physical and chemical status of soils (Managecraft, 2001). Coco-Peat is a finely processed coconut husk, produced from the inner fibers, pith and organic grits, and this accounts for its high moisture retention characteristics. The short life span of organic soil conditioners has led to increase interest in synthetic soil conditioners.

The influence of synthetic soil conditioners on the growth of plants have, so far, been investigated using linearly polymerized polyacrylamides that have, rather, low content of carboxylic groups (De Boodt, 1975; Azzam, 1980; Wallace & Nelson, 1986). New generations of soil conditioners are highly cross-linked polyacrylamides with 40% of the amides hydrolyzed to carboxylic groups. These polymers do not interact directly with the soil matrices but form aqueous gels and act as water reservoirs for the plant-soil system. The roots of the plant grow through the matrix of these hydro-gelled particles and draw water from them when required. Quchi *et al.* (1989) and Bouranis *et al.* (1995) have shown that water held by potassium-based polymer is completely available to plants. Sodium-based polymers are observed to have lower hydration capacity compared to that of potassium-based polymers (Bowman *et al.* 1990).

The introduction of potassium-based copolymers, Terawet (T-200) dramatically increased the water retention capacity of the soil by 400 times its weight and absorbs it faster than all its predecessors. Unlike previous polymeric absorbents, these crystals are able to retain moisture under soil pressure or in the presence of other water-soluble additives. Dehgan *et al.* (1994) showed that amending the growth medium with 0.75% by volume of potassium-based Terawet super-absorbent polymer resulted in application of 50% less irrigation water. The utilization of synthetic polymers resulted in increased tissue nutrients levels concomitant with reduced leaching of some nutrients and runoff (Dehgan *et al.*, 1994; Sweet, 1994). Teraflow, a unique liquid polymeric formulation, also from Terawet Corporation, has similar water absorption capabilities as Terawet. The synthetic product consists of liquid acrylamide copolymer of surfactants, micronutrients, sulfates and sodium asrylate. Teraflow encapsulates water molecules and holds water in the root zone for long periods of time before leaching away.

This pioneering work examines the effects of a natural soil conditioner, Coco-Peat (C-P), a synthetic crystal polymer Terawet (T-200) and a liquid synthetic formulation Teraflow (T-F), on five Ghanaian soil series. The study aims to evaluate the efficacy of the polymeric soil conditioners based on their soil water retention and their effects on the growth performance of maize.

Materials and methods

The experiment was conducted at the University of Ghana Agricultural Research Centre (ARC), Kpong, at an altitude of 18 m above sea level. The mean air temperature is 27.2 °C, with mean maximum and minimum temperatures of 33.3 °C and 22.1 °C, respectively. The relative humidity for the night time to the early hours of the day ranges from 70 to 100% throughout the year. The afternoon relative humidity falls to a range of 20–65% during the year.

The field investigation was a 4 × 5 factorial pot-experiment with maize as the test crop. A randomised split-plot design was used with four replications. The main plot treatment was soil type and comprised five different Ghanaian soil series. Samples of four of these soil types; *Akuse, Amo, Hake* and *Oyarifa*, were collected from the coastal savanna zone and the fifth one, *Akroso*, is from the forest zone. The general description and classification of these soils are given in Table 1. The subplot treatment was polymeric absorbents consisting of four different types: Coco-Peat (an organic polymeric absorbent), Terawet and Teraflow (both synthetic polymeric absorbents) and the control (soil with no absorbents). The general composition and description of the polymeric absorbents are presented in Table 2.

TABLE 1

General description of the selected soils

Soil series	*Classification (FAO, 1990 & USDA*)*	*Parent materials*	*Vegetation*	*Topo-site*	*Texture*
Akroso	Haplic Acrisol (Typic Hapludult)	Biotite granite	Forest	Middle slope	Silty clay loam or silty loam
Akuse	Calcic Vertisol (Typic Calciustert)	Garnetiferous hornblende gneiss	Coastal savanna	Upper-middle slope	Sandy to silty clay
Amo	Gleyic Cambisol (Vertic Endoaquept)	Recent alluvium	Coastal savanna	Lower slope	Silty clay
Hake	Eutric Cambisol (Typic Eutrochrept)	Old alluvium	Coastal savanna	Middle slope	Silty light clay
Oyarifa	Haplic Lixisols (Typic Rhodudalf)	Feruginous colluvium, sandstone, quartzites	Coastal savanna slope	Mid-piedmont loam	Sandy clay

*USDA Classification in parenthesis

TABLE 2

General description of the polymeric absorbents

Name	*Terawet (T-200)*	*Teraflow (T-F)*	*Coco-Peat (C-P)*
Composition or active ingredients	Highly cross linked polyacrylate-polyacrylamide copolymer potassium based	Acrylamide copolymer of surfactants, micro-nutrients, Sulfates and sodium asrylate	Ground coconut husk fibres, pith organic grit and many natural nutrients
Appearance	White granular crystals of size 2000-3000 microns	Liquid, clear to amber	Organic grits, 100% organic medium
Application rate for potted plants	2.67×10^4 kg ha^{-1} m^{-1}	45.5 litres ha^{-1}	Application ratio of C-P: Soil is 1: 4
Mode of application	Mixed with soil below the surface at the root zone of the crop	Surface spray by hose, drip irrigation, overhead and pivot sprinklers	Spread 13 mm over the soil (10 litres/m^2) then dig or rake into soil
Solubility in water	Insoluble	Infinite	Slowly soluble on decomposition
Odour	No odour	Non to mild citrus odour	Pungent scent on decomposition
Longevity	Stable for more than 7 years application	Stable for more than 7 years after a single after a single application	Bio-degradable within 3 years
Hazardous decomposition or by-product	None known	None known	None known

Source: Terawet Cooperation (2000); Managecraft (2001)

The soil samples were air-dried to about 20% (v v^{-1}) moisture content, pounded and passed through a 2-mm sieve. Sixteen identical, conical shaped, plastic buckets were filled with 8.5 kg of the soil samples. The buckets have a height of 0.20 m, a base and top diameters of 0.21 m and 0.25 m, respectively, and perforated at the bottom to facilitate drainage. The buckets were placed on a raised platform. A polyethylene-tarpaulin was provided as an overhead cover for the pots in an event of rains. This was to allow for careful control of soil moisture in the pots. The recommended rates of Terawet, Teraflow and Coco-Peat were applied to the soils in the pots (Table 2), and the pots watered initially to field capacity.

An improved maize variety, Obatanpa, was sown at a seeding rate of two seeds per pot. Soil moisture content was measured by both the non-destructive method with a ThetaProbe and by weighing the pots with the contents on a scale daily to determine the amount of water lost. Moisture stress was imposed on the pots by preventing any form of water into the pots, but allowing the pots to loose water by evapotranspiration for 5 consecutive days. The pots were re-saturated and another set of daily soil moisture readings for 5 days taken for two more consecutive times. The test crop was allowed to grow to its mid-stage (45 days), then harvested, oven-dried at 60 °C to a constant weight for above-soil level biomass determination.

Results and discussion

Water retention

The effect of polymeric absorbents on soil moisture retention is presented in figure 1 with standard error bars. In general, the water retention of Terawet and Coco-Peat treated soils were similar but significantly higher ($p < 0.001$) than both Teraflow and the control treated soils, which were also similar. These results confirm previous observation that polymeric absorbents retain water that would otherwise have been lost by evaporation or percolation (Ouchi *et al.*, 1989; De Boodt, 1990). Teraflow treated soils showed much lower retention than expected, and this might be due to leaching of this liquid polymeric absorbent.

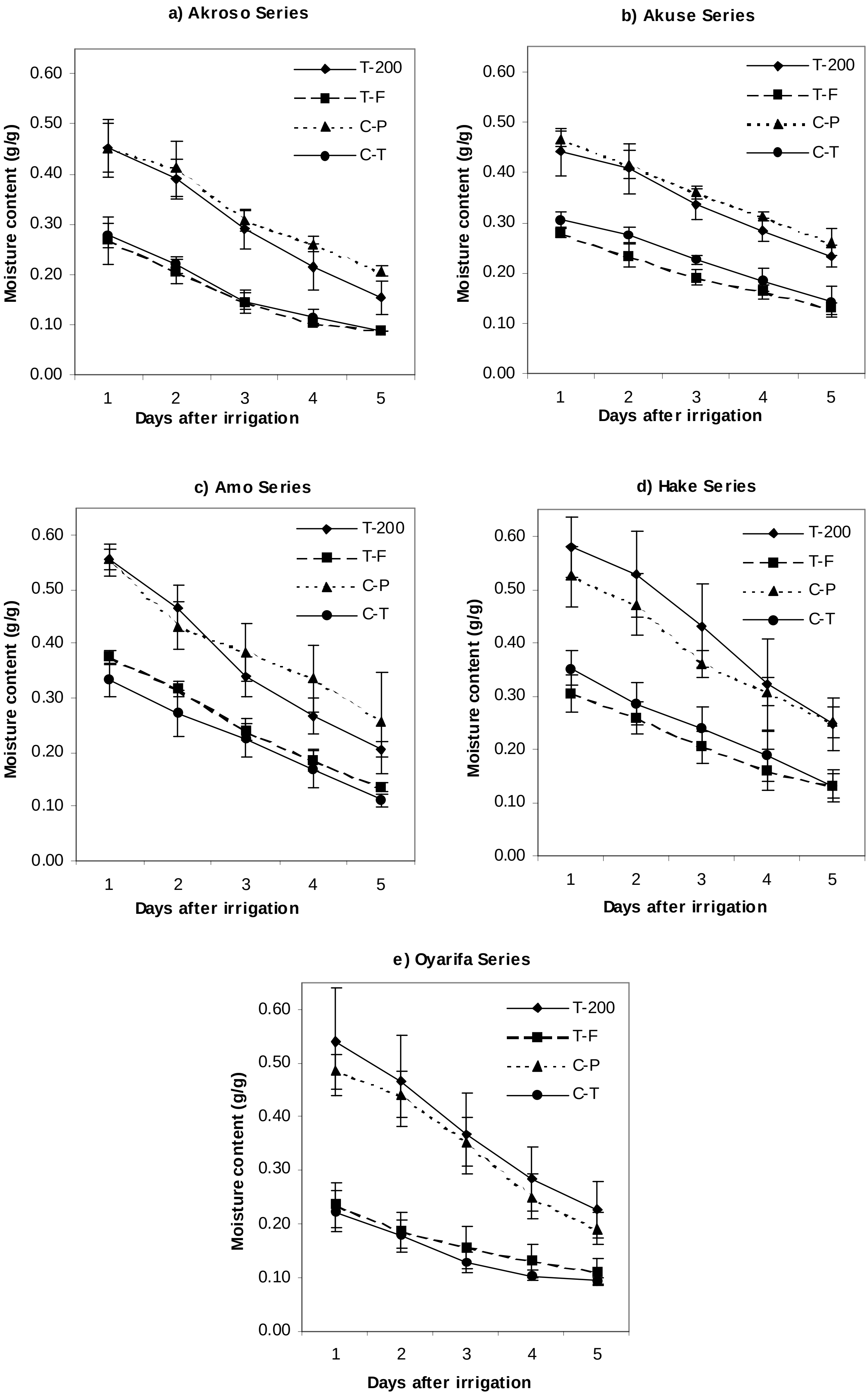
a) Akroso Series
b) Akuse Series
c) Amo Series
d) Hake Series
e) Oyarifa Series
T-200
T-F
C-P
C-T
Moisture content (g/g)
Days after irrigation
0.00
0.10
0.20
0.30
0.40
0.50
0.60
1
2
3
4
5

Fig. 1. Water retention of polymeric absorbents on some Ghanaian soils

The influences of the natural and synthetic absorbents on *Akroso series* are shown in Fig. 1(a). Both T-200 and C-P amended *Akroso series* held water at moisture level of 45% (g g^{-1}), about 61% higher than the control treatment, which is the same as T-F treatment, after the first day of irrigation. This gradually decreased to moisture levels of 15% (g g^{-1}) and 21% (g g^{-1}) for T-200 and C-P respectively after the fifth day of irrigation, corresponding to moisture levels of 66% and 133% higher than both the control and T-F. This shows that, the introduced soil conditioners promoted wide soil moisture ranges within the volume of soil. Evidence provided by Ouchi *et al.* (1989) indicated that the withheld water is almost completely available to plants on continuous basis. De Boodt (1990) showed that this water is subjected not only to gravity by promoting vertical downward movement, but also to lateral suction leading to reduction in irrigation.

Akuse series, with its characteristic montmorilonitic, sandy to silty clays nature (Table 1), showed similar trends like the *Akroso series* (Fig. 1(b)). Treating this soil with polymeric absorbents improved its water retention. The water retention of this soil was in the order C-P > T-200 > C-T > T-F**.** Terawet (T-200) and C-P treated *Akuse soils*, held water at moisture levels of 44% (g g^{-1}) and 47% (g g^{-1}), respectively. This is equivalent to the polymeric treated soils (T-200 and C-P) holding 47% and 57% higher water than the control treatment respectively after the first day of irrigation. After the fifth day of irrigation, these dropped to 23% (g g^{-1}) and 26% (g g^{-1}) for T-200 and C-P respectively, corresponding to a moisture level of 64% and 86% higher than the control. Dehgan *et al*. (1994) observed that, such gradual restricted movement of water, by amending the soils with hydrogels, could result in reduced runoff and leaching of soil nutrients.

For *Amo series*, T-200 retained more water than C-P within the first two and half days after irrigation, but changes after this point with T-200 retaining lesser water than C-P. Both T-200 and C-P retained significantly more water than T-F and the control treatment (Fig. 1(c)). For *Hake series*, the order of the response of the treatments to soil water retention were in the order T-200 > C-P > C-T > T-F (Fig. 1(d)). It is important to note that even these moderately well drained soils were able to retain water, as much as, 24% (g g^{-1}) or about 100% more than the control, after the fifth day of irrigation with the exception of T-F, resulting in the cutting down of irrigation water.

The water retention of the polymeric absorbents on *Oyarifa Series* is shown in Fig. 1(e). Given the sandy nature of *Oyarifa series* T-200, C-P and T-F treated soil held as much as 54% (g g^{-1}), 49% (g g^{-1}) and 24% (g g^{-1}) of moisture respectively, equivalent to 146%, 123% and 10% respec-tively, higher than C-T after the first day of irrigation. These gradually decreased to a moisture level of 156%, 111% and 22% more than the control, after the fifth day of irrigation.

Dry matter yield

The effects of the treatments on biomass production are presented in Fig. 2, with standard error bars. Biomass production on T-200 and C-P treated soils were similar but significantly ($p < 0.001$) higher than those for both T-F and the C-T treated soils, which were also similar. Dry matter yields of 5.4, 5.2, 4.5 t ha^{-1} on T-200, C-P and T-F treated soils, respectively, on Akroso series, were 36%, 31%, 5%, respectively, more than the control treatment, again demonstrating the order of efficacy of the polymeric absorbents. On Akuse series, even though T-200 and T-F gave higher dry matter yields than the control, the differences were not significant, only C-P treatment gave significantly higher dry matter yield than the control, suggesting that the recommended rates for T-200 and T-F may have to be augmented on Akuse series.

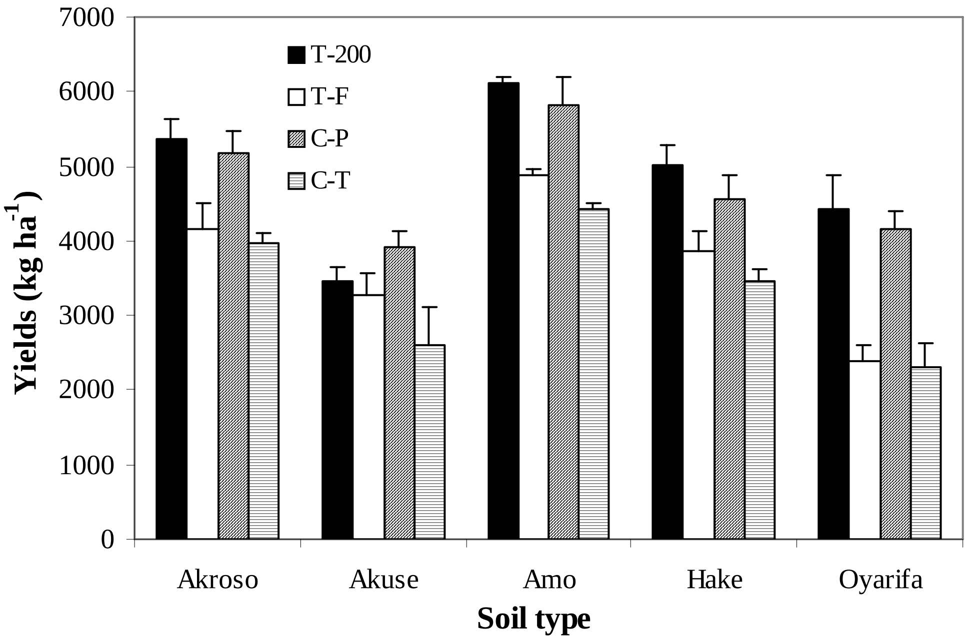

Fig. 2. Dry matter yields of test crop (kg ha^{-1})

However, on the silty clay Amo and Hake series, the dry matter production were very high. On Amo series, the dry matter yields of 6.1, 5.8 and 4.9 t ha^{-1} on T-200, C-P and T-F treated soils respectively, were 38%, 31%, 10% more than the control treatment respectively, whilst on Hake series, the T-200, C-P and T-F treatments increased dry matter yields by 45%, 32% and 12%, respectively.

The highest effect of the polymeric absorbents was observed on the sandy/clay/loam Oyarifa series. The treatments T-200, C-P and T-F increased yields by 92%, 81% and 4% over the control treatment respectively. The trend of the results confirmed the field results from Ouchi *et al.* (1990); Sweet (1994) and Terawet Co-operation (2000) that the differences in yields were due to the improved moisture retention ability of the amended soil by the polymeric absorbents.

Conclusion

The study of soil conditioners on Ghanaian soils showed that the water retention effects of Terawet and Coco-Peat were similar but significantly greater than those of Teraflow and the non-amended soils. The unexpected lower retention of T-F treated soils might be due to leaching of this liquid polymeric absorbent. Biomass production of T-200 and C-P treated soils were similar but significantly higher than those for both T-F and the control treated soils, which were also similar.

Soil moisture retention of polymeric treated *Akroso* and *Akuse series* showed similar trend. However, on *Akuse series*, even though T-200 and T-F treatments produced more dry matter yields than the control, the differences were not significant, suggesting further investigation on the recommended rates for T-200 and T-F on this soil series. The moderately well drained *Amo* and *Hake series*, when amended with T-200 and C-P, were able to retain water by as much as 100% more than the control after the fifth day of irrigation. The highest effects of the polymeric absorbents were observed on the sandy/clay/loam *Oyarifa series*.

The management of waste plastic products in the Ghanaian environment is an alarming problem. These materials can be recycled to produce polymeric absorbents for use in crop production. Research in this regard is therefore highly recommended.

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